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DOI
10.1016/j.envsci.2021.09.021

Publication date
2022

Document Version
Final published version

Published in
Environmental Science and Policy

Environmental Science and Policy 127 (2022) 293–302

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

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A R T I C L E I N F O

Keywords:
Nature-based solutions
Uncertainty
Institutional readiness

A B S T R A C T

This paper explores the concept of “institutional readiness” (IR) applied to the adoption and mainstreaming of Nature-based solutions (NBS) to deal with climate related risks. We argue that barriers towards up-scaling and mainstreaming of NBS are a manifestation of uncertainty, and are often associated with the ‘readiness’ of the institutional setting rather than with the readiness of the NBS technology itself. We align the concepts of Institutional Readiness (IR) to the more widely used concept of Technology Readiness Level (TRL) to understand drivers and barriers for adoption of NBS and analyse the role of institutional capacity. We illustrate this with the case study of the Urban Water Buffer Spangen in Rotterdam, the Netherlands, which is an NBS with high TRL. To do so, we constructed a timeline of the design and implementation process of the NBS, identifying and classifying key uncertainties as well as the strategies applied to deal with these uncertainties, particularly in the institutional context. Our results indicate that for mainstreaming of NBS, Institutional Readiness (IR) should be at a degree where strategies to deal with uncertainties in institutional, organizational and governance contexts can be integrated in the design and planning process. We claim that the concept of IR should be considered in its role to deal with uncertainty, in order to close the documented gap of NBS implementation and mainstreaming.

1. Introduction

Climate disruption and ecosystem degradation are changing the hydrological system at the same time as population and infrastructures increase their dependence and exposure to it (e.g. Di Baldassarre et al., 2018). The increasing frequency, intensity and severity of extreme weather events (O’Gorman, 2015) resulting in a growing magnitude of water related extremes such as droughts and floods has been well documented (IPCC, 2021; Mazdiyasni and AghaKouchak, 2015). These events do not only impact human life, but also the functioning of ecosystems and the socio-economic development that relies on it. In order to increase social, financial and ecological protection from extreme events, scientists have focused in the last decades on the high potential of ecosystem service thinking (Ferraro and Simpson, 2002) in managing climatic variability and impacts. The operationalisation of this potential is further explored in what are called “*nature assurance schemes*” where vulnerability to disasters can be reduced through the “*delivery from and resilience of fully functioning ecosystems*” (Denjean et al., 2017). In general, great efforts are carried out towards nature inclusive approaches (Pahl-Wostl et al., 2007) that promote the maintenance, enhancement and restoration of biodiversity and ecosystems with the objective of increased resilience of our systems (Augeraud-Verón et al., 2017;

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https://doi.org/10.1016/j.envsci.2021.09.021
Received 24 June 2021; Accepted 27 September 2021
Available online 9 November 2021

Baumgärtner, 2008).

The concept of Nature-Based Solutions (NBS) has gained notoriety in the past years (Ruangpan et al., 2019), and has been increasingly utilized as an overarching framework in ecosystem management for sustainability, societal benefit and human well-being (Nesshöver et al., 2017). NBS are considered to have increased adaptive capacities, sustaining a positive impact regardless on how the climate changes (Rizvi et al., 2014), while presenting several characteristics to cope with uncertainty of climate change: flexibility, cost effectiveness and multi-purpose (European Union, 2015). Despite the interest in policy circles and the widely documented and accepted advantages of NBS (Raymond et al., 2017), there are still difficulties in the uptake and general acceptance of NBS by stakeholders, policy development actors, and implementation partners as compared to traditional engineering solutions and technologies. Barriers are identified in natural (biophysical), technical and social systems. All these barriers can be related to uncertainties and how they are managed (Dourojeanni, 2019).

In general, policy-makers and stakeholder at large often seek and prefer solutions that conduce certainty in outcome (Bradshaw and Borchers, 2000; Prins, 2006), with initial aversion and lack of receptivity towards new technologies (Rojas-Méndez et al., 2017). This aversion and lack of receptivity is usually presented in the design stage and is commonly imposed by the complexity, variability and sometimes high and irreducible uncertainties in new technologies and their application. Uncertainties are particularly inherent to the use of ecology and natural dynamics in design (Bergen, Bolton, & Fridley, 2001); as the organisms at the heart of NBS are living and growing, their behaviour and performance can change over time. Uncertainties are however also extended to the technical and social systems in which they will be embedded (van den Hoek et al., 2012). (Garmestani and Benson, 2013; Zandvoort et al., 2018) for example, illustrate the importance of how legal frameworks and more general of how institutional and governance contexts deal with uncertainty. Social uncertainty for implementation of new technologies also manifests itself as part of the science-policy gap (United Nations Environment Programme, 2017), namely in the obstruction of scientifically sound and economically feasible solutions when they are not accepted or validated in social and political terms. (Brugnach et al., 2008) present different types of uncertainty in a system: related to the unpredictable behaviour of nature, humans or the system or simply *unpredictability*; imperfection of knowledge, inexactness, approximations and ignorance, also known as *incomplete knowledge*; and equally valid interpretations of a phenomenon, also known as *multiple knowledge frames or ambiguity*.

Imada, 2017; Dourojeanni, 2019 apply this classification of uncertainties to NBS implementation, distinguishing the natural (e.g. natural dynamics such as weather), technical (e.g. response of the technology on extreme weather conditions) and social system (e.g. economic, cultural, legal, political, administrative and organizational aspects). They show that uncertainties in the natural and technical system are strongly recognized in earlier stages of developing NBS, whereas most of the uncertainties are actually linked to the social system. Social system uncertainties are therefore seen as determinants for NBS implementation (van den Hoek et al., 2012). In a similar vein, uncertainties around unpredictability and incomplete knowledge are well recognized, whereas main uncertainties acting as implementation barriers are those related to multiple knowledge frames (Dourojeanni, 2019; Thorne et al., 2018), which are nevertheless the least accounted for in project development (Jensen and Wu, 2016; Zandvoort et al., 2018).

1.1. Understanding the uptake and adoption of NBS through overcoming barriers

Current research on approaches dealing with barriers for NBS implementation is focused on identification (Barton, 2016; Biesbroek et al., 2013; Guerrin, 2014; Koppenjan, 2015; Mathews et al., 2015; O'Donnell et al., 2017) and management (Biesbroek et al., 2013; Holstead et al., 2016; Waylen et al., 2017) of those barriers. The existing approach to NBS adoption and upscaling (e.g. through research and EU Horizon 2020) uses the framework of Technology Readiness Levels (TRL). The TRL is a concept developed by the NASA in 1974 and has been further operationalized and applied in various fields (e.g. medicine (Webster and Gardner, 2019); industrial applications (Styring et al., 2014); in NBS (Katsou et al., 2020; Langergraber et al., 2020)). It sets nine sequential levels of technological readiness for an emergent innovation to assess its maturity. In research programmes such as EU Horizon 2020 and its sequence Horizon Europe, TRL is adopted to guide research progress. However, the way in which the TRL concept is used, is still subject of debate due to problems in its application related to "system complexity, planning and review and validity of assessment" (Olechowski et al., 2015).

So whereas tools are available to tackle knowledge uncertainties (TRL), there is much less understanding of how to deal with social uncertainty and ambiguity. The latter requires coping with the unavoidable differences that may be generated by conflictive opinions and diversity of interests, values and beliefs among stakeholders. One possibility is to look into social risk perception. (Giordano et al., 2020) use participatory modelling to detect sources of ambiguity in risk perception and relate it to differences in perceptions of risk, understanding of NBS roles and preferences over NBS' co-benefits to be produced. In line with the work of (Kolleck, 2013; Siegel, 2009), they demonstrated that ambiguity in risk perception does not necessarily constitute a barrier to NBS implementation when emerging trade-offs and related conflicts between different NBS beneficiaries are addressed. In case of ambiguous risk perception, the transition from conflict to cooperation calls for actions that stabilize the interactions among the different decision-makers and stakeholders.

From a broader perspective we consider institutional readiness (IR) to deal with social uncertainty and ambiguity typically related with new development/technology and presumably more so with NBS. The IR concept has originated from the field of philanthropic studies to understand which features and characteristics are more likely to improve the 'success' of an organisation (Barnes and R.E, 2006). (Webster and Gardner, 2019) mobilised the concept in regenerative medicine to examine how novel technologies are enabled, embraced, or marginalized through practices, routines, resources and its institutional domain. Building on science-technology studies on adoption and uptake (e.g. Bates and Clausen, 2020; Webster and Gardner, 2019), their research shows that the strength of IR relies on the limitations of the TRL concept. When it comes to understanding the 'natural and social' factors that shape the development and adoption technology, TRL falls short. This is because TRL focuses on the inherent technology performance and does not engage with its surrounding and changing context, presuming that the context of the technology application is fixed. It is however equally relevant to understand how new technologies are engaged with, and made sense of, particularly through organizational processes and institutional structures. Indeed, a higher TRL level does not always imply readiness for implementation; the technology might in fact not be mature to adopt in certain contexts or systemic conditions. Context however matters, and (May et al., 2011) show that normalisation of new techniques or technologies is process driven, changing and reshaped over time. Institutional incompatibilities need to be detected in order make concrete policies effectively implementable, through changes in formal and informal institutions (Hauck et al., 2019).

Implementation studies in the field of (potentially nature-based) water management by e.g. (Godinez-Madrigal et al., 2020; Van Cauwenbergh et al., 2018) confirm that context is important, that implementation is process-driven and that the ability to handle different natures of uncertainty is key.

We bring the concept of institutional readiness to the field of nature-based climate adaptation and intend to understand the articulation between the provisionally ready technology, and the emerging organizational framework that can handle uncertainties in NBS adoption and implementation. Our hypothesis is that the implementation of NBS for hydro-meteorological risks may be facilitated when key uncertainties are identified and subsequently managed. This would entail the existence of proper mechanisms embedded in institutional and organizational arrangements to apply strategies to either reduce or cope with those uncertainties. To assess our hypothesis, it is important to understand how uncertainties in the implementation of NBS are currently managed. In this research, we do so by analysing a specific case with a mature technology NBS (at TRL7, meaning it is an actual system prototype in an operational environment): the Urban Water Buffer in the neighbourhood of Spangen in Rotterdam.

The present research aims to answer the following questions: (1) to what extent can institutional readiness (IR) explain the (lack of) uptake and adoption of NBS, (2) how does this relate to the management of uncertainties and (3) how can the concepts of IR and uncertainty management be used to help mainstream NBS for hydro-meteorological risk reduction? We aim to answer these questions through the in-depth case study in which first, we detect which uncertainties are the most significant for implementation partners, policy-makers and stakeholders in general. Based on existing methods to identify, understand and classify uncertainty developed by (Brugnach et al., 2008; van den Hoek et al., 2012), we then detect and identify strategies applied to reduce or accommodate uncertainties (Dewulf and Biesbroek, 2018; Jensen and Wu, 2016). This framework gives us the basis to analyse key strategies applied in this context that permitted to address the main uncertainties detected. We finally relate the application of the strategies in the institutional context to institutional readiness to analyse its importance for NBS implementation.

2. Materials and methods

2.1. NBS case study: urban water buffer in Rotterdam, The Netherlands

The Urban Water Buffer is located in Rotterdam, the Netherlands and is an innovative pilot project to collect, filter, store and re-use stormwater for the irrigation of a sports field in the nearby Sparta Rotterdam Stadium. Located in the district of Spangen, the development and final implementation lasted around two years, until its construction ended in January 2018. This NBS is innovative in its use of an urban aquifer storage - through the purification of retained storm water through a bio filtration system prior to infiltration – and its monitoring and operation principles. The system is designed to treat, infiltrate, retain and deliver 15.000 m^3 /year of water to the adjacent sports field. At the same time, the bio-filtration system and the aquifer storage complies with the spatial improvement and increased retention capacity of the area respectively. This set of characteristics give the UWB project a multi-objective/multi-benefit and nature based approach towards hydro meteorological risk reduction. Fig. 1.

As a pilot, the Urban Water Buffer project is monitored extensively after its implementation in order to assess whether it complies with current regulations (e.g. water quality after bio-filtration), combines benefits for society (e.g. spatial improvement) and presents a business case that can be up-scaled and applied in other 'urban areas'. At the same time, the UWB project was surrounded by great levels of uncertainty related to natural system dynamics (e.g. behaviour of the system under long terms of drought), technical (e.g. ability of the system to comply with current regulations) and particularly social (e.g. acceptance by the local community). We analysed the characteristics of the implementation process and its ability to deal with uncertainties to assess the role of institutional readiness in the implementation of NBS.

2.2. Analysis of uncertainties and strategies

Uncertainties are identified through qualitative research based on document analysis and interviews with key stakeholders in the implementation process. We started with a document analysis of key policies and planning strategies to implement NBS in specific contexts. These documents help to understand the institutional context and support (or absence thereof) for NBS implementation. Following Imada (2017), van den Hoek et al. (2012), uncertainties were detected using a list of keywords and topics. Second, six interviews were conducted to main project actors between December 2017 and January 2019. We elicited understanding of their perspectives on barriers, uncertainty and enabling factors and/or strategies to cope with uncertainty in NBS implementation. A timeline mapping method (Kolar et al., 2015) guided and complemented these interviews and was used to uncover uncertainty situations in different stages of the planning process following (Loucks

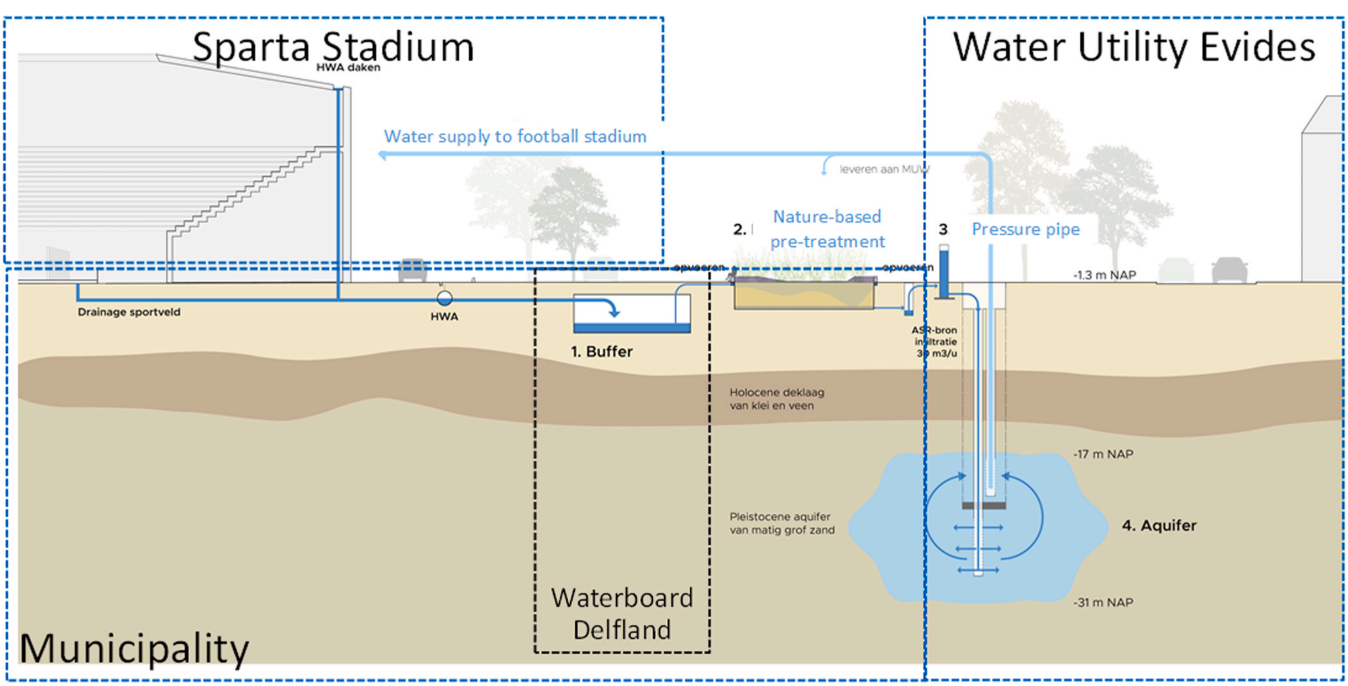

Fig. 1. Scheme of the Urban Water Buffer in Rotterdam.

and van Beek, 2017): inception, situation analysis, strategy building, action planning and implementation. A Grounded Theory (Glaser and Strauss, 1967) approach allowed important issues to arise from the data and generated a final list of uncertainties. These uncertainties were then classified in the uncertainty matrix (Table A1 and A2, supplementary material). Thirdly, and based on the nature and system of uncertainties identified, case-based strategies for coping with uncertainty were corresponded to strategies found in the literature (Table 1). Lastly, new strategies in the development process were identified (as seen in bold in Table 1).

2.3. Assessment of institutional readiness (IR)

Based on this study, we connected and related the strategies utilized with the key aspects and categories of Institutional Readiness in order to identify and understand how the organizational framework handled (or not) uncertainties in the development process.

The eight categories shown in Fig. 2 are not sequential levels such as in TRL, but rather characteristics that are present at different levels of maturity. Another key difference with TR, is that the IR concept believes implementation of novel technologies requires trial and error, rather than solely the incorporation of an already working technology. IR builds on the notion that adoption occurs via normalisation rather than via the assessment of technology maturity and the materiality of the technology is co-produced (Webster and Gardner, 2019). To assess the institutional readiness in our case, we converted the operationalised definition of IR categories into questions (see Table A3, Supplementary material), and answered them assessing key aspects of the institutional setting in the context of the UWB project development. Finally, we discussed the results with stakeholders, and proposed a series of indications to aid in the implementation and mainstreaming of NBS, particularly for the improvement of the organizational framework that can handle uncertainty, and therefore, increased the IR for the adaptation and implementation of these solutions.

3. Results

3.1. Development process of the Urban Water Buffer Spangen

Fig. 3 presents a total of (14) key events in the timeline of planning and implementing the Urban Water Buffer and will be detailed in continuation. In its inception, various programs and plans of individuals and organizations set the diagnosis and objectives for future development in the area. Several ideas were studied in this phase. Parallel to the municipality's analysis of the current water resources situation and the existing climate adaptation objectives in policies and plans (1), a local community initiative emerged in the neighbourhood to increase green spaces in the area (2). Their request was answered by the municipal department of spatial planning, which had clear urban development goals mainly due to the growing population and requirements for the spatial development in the area (Field Factors, 2018). These initial ideas were put together by the Urban Water Buffer consortium, headed by the public research institute KWR Water Cycle Institute, with the overarching goal of climate proofing the city.

Interviewees point to two key aspects that allowed the integration of these objectives: the existence of an innovation fund of the 'Top consortia for Knowledge and Innovation Scheme' (TKI) of the Ministry of Economic Affairs - a public-private consortium that aims to conduct user-oriented research that supports the implementation of innovative technologies - and the presence of key players engaging with new NBS technologies while meeting their own organizational needs. The latter was key as to converge the different objectives of stakeholders and organizations at initial stages of the process (3). The TKI fund supported the process of implementation, especially through studies for the location, the preliminary design and budget of the installation of the system (Field Factors, 2018). The integration of climate adaptation measures and inclusion of various stakeholders and parties was supported by the TKI consortium, the Municipality of Rotterdam and water board Hoogheemraadschap van Delfland (4). Prior to the idea of the project itself, various stakeholders shared concerns related to the uncertainty of the response of an innovative solution and the funding mechanisms for long term maintenance. The difficult laid in integrating all these aspects in the design. In this stage, organisational needs were put together through (5) the alignment of the expectations of citizens, decision makers, and market through instances of dialogical learning and collaborative decision making. In this sense, this work involved a creative and innovative process, which deviated from standard procedures and implementation paths of conventional solutions and technologies. In this aspect, interviews pointed out to yet another barrier linked to uncertainty: the unknown process of implementation. (6) In addition to the inclusion of parties intending to fulfil the objectives of increasing the water retention capacity (Municipality and Delfland water board) and green areas (Municipality and community), two other important actors were also involved. (7) The integration of Sparta Rotterdam soccer stadium to the project happened at an early stage through an invitation of the local community.

Since extreme rainfall provoked a series of problems for the stadium soccer pitch, they saw an opportunity to reduce the flood risk and at the same time add a new source of water for irrigating their soccer pitch. On the other hand, (8) (9) the integration of Evides Waterbedrijf to this process also happened at an early stage, mainly triggered by the opportunity raised by the Water Board in the initial stages of the process to incorporate the retained water into Evides' system (10). The decision to follow a business as usual planning process (11), or to push for an innovative solution that involves a cross sectorial process appeared to be a difficult process. (12) This was particularly a concern from within the municipality, where different departments had their own strategies. This behaviour is described by other stakeholders as silo thinking and proved to be a barrier as there was no prior experience of implementation of this sort of solutions in place. This called for an innovative process that would be able to create the communication channels between the different actors and working grounds. In order for this to happen, two important factors had to converge: (i) the TKI fund was key at assessing the capacity to take-on and develop this new technology, and (ii) the commitment of a key actor formally tasked to enable the adoption of the technology, especially in regards to meeting standards and procedures. Finally, the construction of the UWB Spangen took place in 2018, but as we could evidence, the process of implementation was not without difficulties. Barriers and uncertainties were present along the process of implementation, but they were managed by a different set of strategies along the process, integrated in organizational setups.

3.2. Uncertainty assessment and coping strategies

Table 1 gives an overview of the different types of uncertainties in the design and implementation process. We identified how they manifested as a key barrier and what was the coping strategy and key success factor to manage the uncertainty and overcome the barrier. The analysis indicates that most uncertainties detected and identified by stakeholders and implementation partners are related to the social system (10 out of 14).

The uncertainty in the technical system is mainly related to the physical performance of the NBS: how will it respond to high/low levels of precipitation, will it respond to the current situation and would it be a better solution than the conventional/grey infrastructure? While the first two uncertainties were managed through the creation of a test site, which relates to the TRL, the latter was managed through awareness raising and co-design of the NBS.

From the 10 observed social system uncertainties, 3 are related to unpredictability (on community response, regulatory evolution and socio-economic conditions), 5 are on incomplete knowledge (stakeholder representation, information sharing, implementation and finance

Table 1
Uncertainties, barriers and coping strategies/success factors for UBW implementation.

Dim		Uncertainties found	Key barrier	Key success factor	Coping strategies: literature and new (in bold)
Unpredictability	**T**	(1) What will be the response of the NBS in events of high and low precipitation?	Uncertainty of innovative solution.	– Test site to make visible the compliance of the innovative NBS toward different climatic scenarios.	– Develop solutions robust to multiple possible futures. – - **Scalable projects to monitor and prove the technology in the largest range of variations.**
	S	(2) What will be the response of the community towards the solution?	Different problems/ interests from stakeholders	Co-design and involvement of the community.	– Take mitigation measures to reduce the negative effects of undesirable scenarios. – - **Involvement of all stakeholders in instances of decision making.**
		(3) Will the NBS comply with current and future regulations regarding water quality?	Uncertainty of innovative solution.	Test site to make visible the compliance to current water quality regulations.	– Install short cycles of monitoring and adjustment. – - **Pilot project for continuous learning and adaptation.**
		(4) What will be the future economic and social conditions?	Unpredictable future scenarios.	Not considered.	– Apply temporary adaptation strategies.
Incomplete Knowledge	**T**	(5) Will the solution respond to the current situation?	Uncertainty of innovative solution.	Test site for monitoring and data gathering.	– More data gathering and research to complete lack of knowledge. – - **Pilot project for continuous learning and adaptation.**
	S	(6) Are all the stakeholders considered or involved in the decision making process?	Different problems/ interests from stakeholders.	– Champion, agent of change. – - Involvement of stakeholders by other parties.	– Use of expert opinion. – **Identification of new stakeholders, not only those that are directly related with the project.** – **Improve communication and coordination between scientists, decision makers and other stakeholders.** **- Agent of change, mediator, and coordinator for the engagement**.
		(7) Unknown holders of information and lack of information sharing (Silos)	Information silos	Attention to the interactions of the knowledge, defined by the project responsibilities.	– More data gathering and research to complete lacking knowledge. – Dialogical learning and shared involvement. – **Identify the information channels and coordination among stakeholders (considering formal and informal channels).** – **Clear responsibilities, adding information sharing responsibilities.** – **- Move from incomplete knowledge to multiple frames of knowledge, and accept that stakeholders look at the situation from a different perspective.**
		(8) How should we implement this kind of solution?	Uncertainty of innovative solution	– Champion, agent of change. – Objectives set in the Water Resilient Rotterdam program.	– Expert opinions. – More data gathering and research to complete lacking knowledge. – **Involvement of key stakeholder (agent of change) to guide the implementation.** – **- Expert opinion to guide the process (in all stages).**
		(9) How should this solution should be financed?	Uncertainty of innovative solution	TKI project support and funding for the process of implementation.	– **Funds to support the process of implementation.** More data gathering and research to complete lacking knowledge.
		(10) What are the co-benefits of this solution?	Uncertainty of innovative solution	Workshop for identification of co-benefits.	– Expert opinion. – More data gathering and research to complete lacking knowledge. – - **Identification of co-benefits (should be in earlier stages).**
Multiple knowledge frames	**N**	(11) Is the problem not enough green areas, or hydro-meteorological risk?	Different problems/ interests from stakeholders	Identification of problem and problem framing.	– Effective communication – **- Integration of concerns and problems of different stakeholders.**
	T	(12) Should we build infrastructure as we usually do (business as usual) or pursue innovation (NBS)? (Alternative solutions).	Uncertainty of innovative solution	Raising awareness and co-design.	– Effective Communication. – **Rather than focusing on different frames, gather information that can alter the nature of the discussion.** – - Discussion of trade-offs among different NBS beneficiaries.
	S	(13) What are the criteria's to monitor and evaluate the co-benefits?	Different problems/ interests from stakeholders	Definition of co-benefits and indicators.	– Effective Communication and negotiation approach. – **Definition of criteria at an early stage of the process (Inception), with expert elicitation.** – **Integration of other stakeholders (community).** – **- Dialogical learning approach should be considered to select criteria and raise awareness.**

(*continued on next page*)

Table 1 (*continued*)

Dim	Uncertainties found	Key barrier	Key success factor	Coping strategies: literature and new (in bold)
	(14) To whom should the management of the NBS be transferred?	Uncertainty of innovative solution	Clear delimitation of responsibilities and tasks at an early stage, involving all stakeholders.	– Persuasive Communication and negotiation approach. – **- Definition of responsibilities and tasks, sharing of information about mandates (and potential need for institutional change), definition of end-users and funding.**

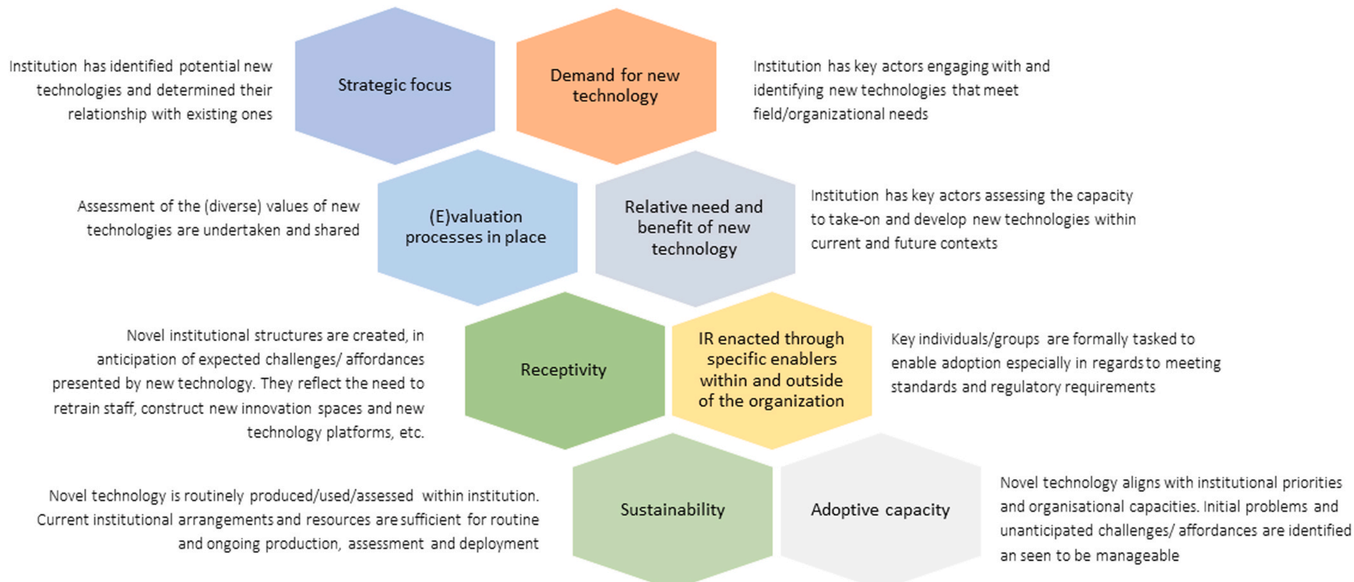

Fig. 2. The eight key aspects of Institutional Readiness. Adapted from (Webster and Gardner, 2019).

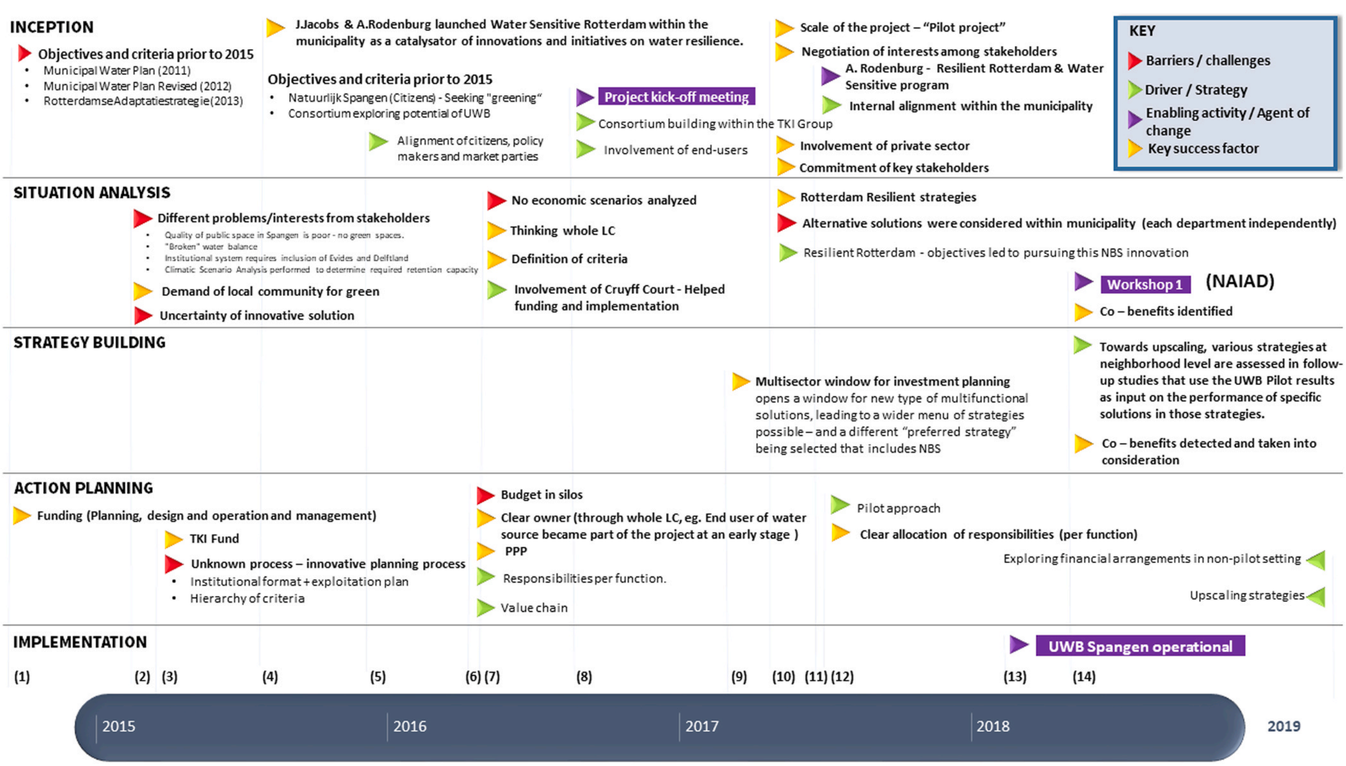

Fig. 3. Timeline of UWB-Spangen NBS planning and implementation – (numbers) on the timeline indicate key events discussed in results. The timeline shows an iterative instead of linear and chronological process of implementation, revisiting earlier components in advanced stages of the process. Source: (Dourojeanni, 2019).

unknowns and uncertainties on the co-benefits) and finally 2 uncertainties are on ambiguity or multiple knowledge frames (monitoring criteria and who should manage the NBS). In the coping strategies and key success factors we see a number of elements that are related to institutional readiness. Not only is the involvement of stakeholders, knowledge sharing and awareness raising an important factor, analysis of our case also shows the importance of agents of change to drive the process. In addition, the existence of a policy framework that can leverage certain actions (e.g. Water Resilient Rotterdam programme) is crucial to overcome barriers on implementation uncertainty.

For a detailed account of the results, we refer to Dourojeanni (2019).

4. Discussion

4.1. Analysis of institutional readiness

Analysis of uncertainties and institutional readiness in the UWB case show that uncertainties in the different systems (natural, technical, social) can only partly be addressed by the concept of TRL. Most uncertainties relate to the institutional set-up in terms of existing policies at different scales and the championing of context-based processes that address stakeholder concerns and gaps in the implementation setup.

In the UWB case, there is a clear **demand for new technology** from key actors, such as the TKI consortia. The task to fit these new technologies into organizational needs involved the presence of stakeholders that supported the necessary communication and coordination mechanisms to prevent certain barriers to hamper the process, such as silo thinking, lack of intersectorial collaboration, un-identified stakeholders and lack of funding mechanisms. NBS implementation is a complex issue, which success does not depend exclusively on the capacity and resources of the involved stakeholders, but also on the number and quality of the relationships with each other. Quality matters, as ambiguity in values, beliefs and problem frames may lead to collaboration structures that encourage stakeholders to avoid each other, turning the participatory process into a controversial and futile one. Interviewees in the case of the UWB point out to a key individual from the municipality that managed to adequate the technology towards the fulfilment of risk reduction and urban development objectives (**relative need and benefit of new technology and enablers within and outside organization**). The co-design of the measure seemed key as to **adopt the technology** in order to fit to different objectives and needs of other organizations. In this sense, the institutional setups prove to be important to establish collaborative governance approaches that appeal to a consensus oriented and deliberative approach that focus on common interests. Through effective interactions and communication, different decision-actors tend to align their problem frames, adjusting goals and actions to achieve mutual benefits. Although this process is not embedded in a current organizational structure, it was managed through the development of the project by the stakeholders that implemented the NBS, or in other words, its institutional structure.

Regarding the **strategic focus**, potential measures are identified through municipal and city plans. These plans describe These plans describe in general terms how different stakeholders (municipalities and water boards) want to deal with water issues in the city, such as water safety, water storage, sewerage, water quality and groundwater. The main objectives are to solve various water challenges, while contributing to the attractiveness and climate-proof city. In practice, it sets a number of responsibilities and objectives, together with a set of clearly defined projects (such as NBS) to be developed. At the same time, there are currently prevention and preparedness strategies in place under national disaster risk management plans that take into account impacts and projections of climate change. In regards with the **assessment of the (diverse) values of new technologies**, at EU and national level to value the benefit of NBS, particularly targeted into co-benefits and insurance valuation of ecosystems. Particularly key seem the setting of the business case for NBS, in what responds to defining how value is created and who is (willing) to pay for it. **Monitoring and (e)valuation** is however a weak point in the IR in this case. No changes were made to the dispersed responsibilities and no funding was foreseen to put a **structured and continued monitoring process** in place. This jeopardizes wider **sustainability** of NBS, even though expertise is clearly built up and shared through the projects, it is not backed up with structured evidence on performance of prior projects. Transfer of knowledge in a larger pool of organizations therefore risks to be bound by the trust in particular agents of change. Fig. 4 summarizes the case-based operational definition of the different IR categories for NBS implementation.

4.2. Institutional readiness and uncertainty management – keys to understand NBS mainstreaming

Our results confirm the argument by Webster and Gardner (2019) that IR is “about marshalling trans-organisational expertise and participation in helping to ‘ready’ diverse actors to undertake more workable, doable technological innovation” and that “the actual value of TRLs will depend on how well they incorporate a focus on (trans) organisational integration”. Our uncertainty analysis and timeline methodology further highlights the importance of an adaptive management approach that promotes NBS in institutional and governance structures to facilitate NBS implementation and uptake. Although attention for ambiguity was lacking in the design phase, the mechanisms set for deliberation and conflict resolution in a trans-organizational setting enabled the use of strategies capable of dealing with the main barriers found (see Table 3). In this sense, the results of this paper intend to further evidence the embeddedness of strategies applied in the case study to manage and reduce uncertainties via intra and extra organizational dimensions of adoption and implementation. While recent policy and funding initiatives have created momentum towards a more enabling environment for NBS, key institutional structures are yet to appear for NBS mainstreaming. Articulation is needed between provisionally ready NBS technology, and the emerging organizational framework that can handle uncertainties in the adoption and use of NBS for hydro-meteorological risk reduction. This is likely to require a new overall accountability and risk framework, as operationalized in the IR category on receptivity. Without this, it is likely that there will be considerable difficulties in regard to NBS adoption and implementation.

The results show that the concepts of IR and uncertainty are useful to understand the (lack of) adoption of NBS. The proposed methodology (timeline mapping and uncertainty classification) provides useful insight in drivers and barriers for NBS implementation that need coping strategies embedded in a general institutional readiness. The IR analysis method can be used to understand NBS implementation and IR in broader cases, even though the uncertainty classification may be considered subjective as it involves interpretation by interviewee and researcher, confirming earlier observations by (Imada, 2017). Nevertheless, some limitations were found in the IR concept to understand how NBS are implemented and mainstreamed. While the concept of receptivity does account for the presence of novel institutional structures to build capacity and respond to challenges in the implementation process, it falls short in providing substantial information on the funding and financing of NBS. In the field of regenerative medicine, (Webster and Gardner, 2019) document evidence of rapid growth of large-scale financing mechanisms and the creation of organizations and regulatory vehicles for the creation of pathways for new developed treatments as receptivity and sustainability. While similar dynamics are seen for NBS (e.g. EU Sustainable Finance Taxonomy, incorporation of NBS in climate NDCs (Swann et al., 2021)) funding and finance of NBS is more complex. It typically involves a mix of public and private benefits over a multitude of actors and sectors and often facilitated through blended finance and funding (Altamirano et al., 2020). Further research should unpack the categories of receptivity and sustainability in this regard and explore the concept of investment readiness to do so as proposed in (Van Cauwenbergh et al., 2020).

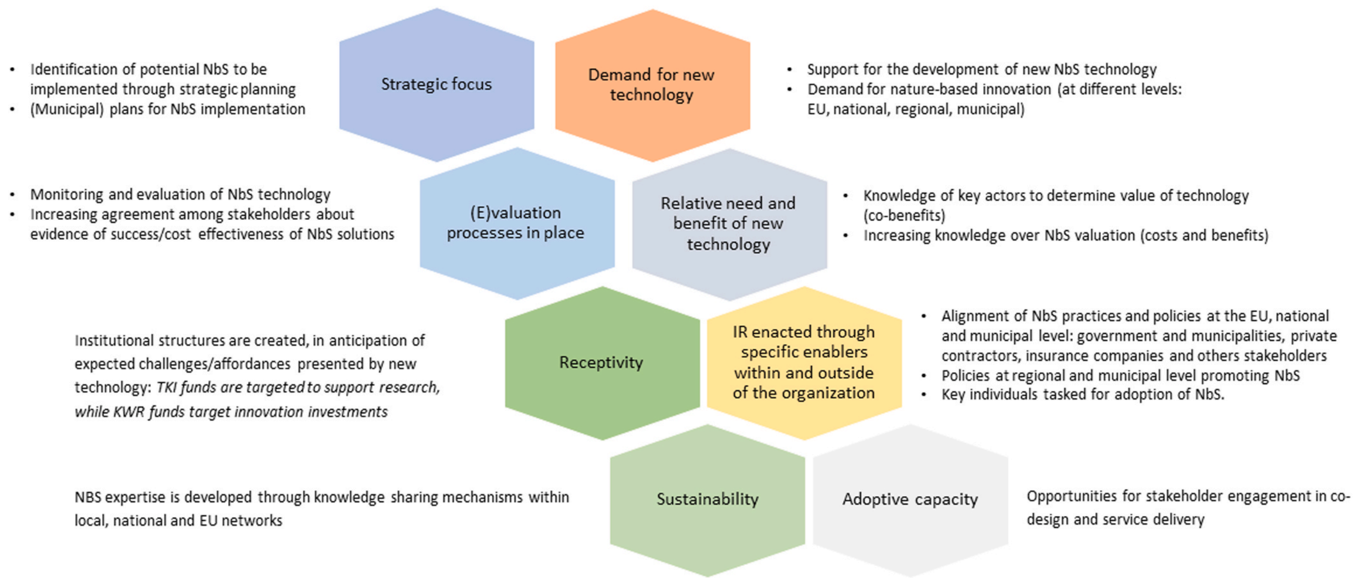

Fig. 4. Operational description of IR categories in the Urban Water Buffer development process.

5. Conclusion

Our research set out to understand the role of uncertainty management and institutional readiness in the mainstreaming of NBS, using the case of an urban NBS in Rotterdam. Detailed document analysis, stakeholder interviews and observations, show evidence of institutional readiness in all key aspects thereof. Institutional readiness is particularly manifested through the way in which uncertainties related to the social system and ambiguity are managed. These uncertainties are represented by a variety of different stakeholders and organizations that utilized strategies in order to cope with uncertainties inherent to NBS adoption and implementation. Even though no sole organization has the capacity to deal with all uncertainties in NBS implementation, support for implementation practices can be fostered through institutional spaces in open, inclusive and transparent governance processes (Raymond et al., 2017). The capability to guarantee the equitable representation of all values and perceptions held by different stakeholders, creates cross-sectoral dialogues that provide legitimacy of knowledge amongst stakeholders (Crowe and Collier, 2016; Kabisch et al., 2016; Raymond et al., 2017), enabling public-private partnerships (Koppenjan, 2015) and knowledge sharing (Raymond et al., 2017). Experiences from our case study reveal that this support may ensure that activities become acceptable to various stakeholders, facilitating present and future implementation of NBS.

A bigger question appears in this respect: do we need consolidated organizations with a specific mandate to support the implementation of NBS? Our research shows collaboration mechanisms were set, and novel but context specific institutional structures appeared. However whether this type of institutional structure will suffice for future NBS implementation is impossible to affirm. The marshalling of trans-organizational collaboration at the core of IR is likely to be a context-specific and iterative process, with agility and flexibility as important requisites to create IR. Indeed IR needs to build on mechanisms and strategies that can continuously adapt and change to new conditions, as identified uncertainties change through time. Depending on context, specific interventions are needed to stabilize the interactions among different decision-makers and stakeholders, contributing to the transition from conflicts to collaboration. Some crafting of IR will therefore remain needed. However, future work on establishing criteria for assessing IR in order to apply it to different contexts of NBS implementation, will facilitate this process. NBS implementation processes are made workable through the practices and capacities of institutions, together with the maturity of the technology – both in terms of TRL and IR. Complementing assessment of TRL with that of IR is crucial to understand how mature technology fits in its institutional context. Finally, our analysis showed the limitations of TRL and IR to deal with financing and funding of NBS, which remains an important barrier to its mainstreaming. Further research should include specific criteria for investment readiness.

CRediT authorship contribution statement

Van Cauwenbergh & Dourojeanni: Conceptualization, Methodology, Investigation. **Dourojeanni**: Data curation, Writing – original draft, preparation. **Van Cauwenbergh & Lopez-Gunn:** Funding acquisition. **Dartee:** Resources. **Van der Zaag, Van Cauwenbergh & Brugnach***:* Supervision: **Van Cauwenbergh & Giordano:** Writing – review & editing,

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors contribution to this paper was undertaken in the context of the Nature Insurance Value: Assessment and Demonstration (NAIAD) project (Grant Agreement no 730497), which is financially supported by the EU Research and Innovation Programme Horizon 2020. We are grateful to all the NAIAD participants for their valuable suggestions. Brugnach was supported by the Spanish Government's María de Maeztu excellence accreditation (Ref. MDM-2017-0714).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.09.021.

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